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Effect of Moisture Stress on the Growth and Yield of Determinate and Indeterminate Types of Soybean

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The effect of moisture stress on determinate (Enrei) and indeterminate (Touzan 69) types of soybean was studied under vinyl house field conditions. Moisture stress seriously reduced the growth, yield and yield components of both soybean types, but the quantitative effects were seen more in Touzan 69 than in Enrei. Although water stress reduced the floral buds and pod setting ratio in both types the differences were not significant. The contribution to the number of pods per plant and seed yield on low and high order racemes was unaffected in Touzan 69, while in Enrei, the contribution to these parameters increased on high order racemes and decreased on low order racemes. In Enrei the contribution to these two parameters on the main stem and branches was not affected by water stress; however, in Touzan 69 the contribution increased 16-18% on the main stem and decreased on the branches. It was concluded that the contribution to the number of soybean pods per plant at different positions essentially mimicked the differences in seed yield. In both soybean types the detrimental effects of water stress on all the yield components resulted in lower total yield. The main difference between both types was that comparatively more reduced growth (less number of nodes/plant) of indeterminate type reduced a greater number of floral buds which also had a synergistic effect on reducing the yield, so ultimately the yield reduced more in indeterminate than in determinate type.

Key words : determinate type, growth, indeterminate type, raceme order, soybean, yield components, water stress.

Introduction

Drought is the primary cause of reduced crop growth on a world wide basis[14]. Soybean is no exception as drought is the most limiting environmental factor to plant height[4] and seed yield[1]. Soil moisture deficit also enhances flower and pod abortion[15].

Irrigation can overcome the problem of low soybean yield as has been thoroughly summarized[1,6,13]. Most of the yield difference between irrigated and nonirrigated soybean was associated with an increase in the number of seeds[5,6]. The point for consideration here is that most studies have been conducted under field conditions and the effects of rainfall cannot be overlooked. On the other hand, some investigations were carried out in pots under rain shed conditions where the actual potential of the plants cannot be compared to that of plants grown in field conditions. Furthermore, comparison of determinate and indeterminate soybean types under drought stress conditions in the liter-

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ature is very scanty. It has therefore not been possible to understand the behavior of these types of soybean under severe drought stress conditions. In soybean, the flowering habit is according to raceme orders[9], so it is reasonable that the effects of moisture stress in this crop may vary according to raceme orders on the main stem and branches. In order to abridge the above-mentioned gap in drought stress studies in the soybean crop, a trial was set up to evaluate the growth, yield and yield components behavior of determinate and indeterminate types of soybean according to low and high order racemes on the main stem and branches under severe drought stress in vinyl house field conditions.

Materials and Methods

The water stress studies were conducted at the Research Farm of Okayama University in 1997. The texture of the soil was sandy clay and the preceding crop was also soybean. Enrei (determinate) and Touzan 69 (indeterminate) cultivars were used as experimental materials. Sowing of the crop was done on 17th June with a net plot size of $14.4 \mathrm{m}^2$ ($6 \mathrm{m} \times 2.4 \mathrm{m}$) having three rows per plot. The rows were 80 cm apart and the distance between plants was 10 cm.

The experiment was conducted under vinyl house field conditions to exclude rainfall. All four sides of the dry plots were dug down to one meter in depth, gravel was filled at the bottom 15 cm and then plastic sheet was inserted to prevent the percolation of water from the sides. Ground water level was maintained at 80 cm by pumping up the water through underground drainage. All this was done to create severe water stress conditions in the dry plots. The dry and wet plots received a light irrigation immediately after sowing to ensure good germination. Thereafter, the dry plots were not irrigated until harvest, while the wet plots were irrigated with ever flow hoses (in every next row), as and when required to avoid the effects of water stress.

A sample of 14 standard plants was collected at the time of harvesting from each plot and the data on yield and yield components were based on these samples. Special care was used to distinguish the pods on low and high order racemes at the main stem and branches. Seeds were depodded manually and weighed. For the calculation of pod-setting ratio, daily data were recorded from the three selected plants on flowering, flower and pod shedding from the beginning of flowering to harvesting time.

Definitions of the raceme orders were according to Kuroda et al.[9]. Furthermore, terminal (0) and 1st order racemes were classified as low order racemes and those above 1st order racemes were collectively classified as high order racemes.

Results and discussion

A. Growth characters

The data reported in the table 1 demonstrate that water stress reduced the total number of nodes in both soybean types i.e., 24% in Enrei and 55% in Touzan 69 as compared to well irrigated wet plots. The number of nodes on the main stem

Table 1 Growth characters of soybean cultivars as affected by moisture stress

Variety	Plot	No. of nodes/plant				Stem length (cm)	Stem diameter (mm)	Stem weight (g)
		M	Br	Asi	Total			
Enrei	Wet	$12.9 \pm 1.0^{*}$	15.5 ± 4.1^{NS}	$14.7 \pm 2.9^{\#}$	$43.1 \pm 5.2^{\#}$	$66.8 \pm 6.8^{\#}$	$8.49 \pm 0.7^{\#}$	$10.73 \pm 2.0^{\#}$
	Dry	12.1 ± 0.6	13.0 ± 3.1	7.6 ± 2.2	32.7 ± 4.1	50.3 ± 13.4	6.89 ± 0.5	5.84 ± 0.9
Touzan 69	Wet	$21.1 \pm 1.5^{\#}$	$37.1 \pm 9.9^{\#}$	$16.4 \pm 5.0^{\#}$	$76.8 \pm 9.7^{\#}$	$132.0 \pm 11.1^{\#}$	$8.75 \pm 0.7^{\#}$	$19.00 \pm 3.4^{\#}$
	Dry	15.1 ± 2.7	15.3 ± 6.1	4.7 ± 3.2	34.8 ± 11.1	59.7 ± 18.6	5.12 ± 1.0	4.86 ± 2.7

M, Br and Asi indicate the main stem, branch and second order raceme with compound leaf. ^{NS}, * and $^{\#}$ indicate non-significance, 5% level and 1% level of significance between plots, respectively. Mean of 14 plants±standard deviation.

in Enrei significantly decreased with water stress. There was also a slight decrease on branches and about 50% decrease on second order racemes with compound leaves. Compared to Enrei, the number of nodes in Touzan 69 were severely decreased on main stem, branches and second order racemes with compound leaves in the order of branches > 2nd order racemes with compound leaves > main stem. Ultimately the total number of nodes were decreased more in Touzan 69 than in Enrei. These results are almost in agreement with Kadhem et al.[8] in that water stress reduced the number of nodes per plant in soybean with a greater effect in indeterminate types as compared to determinate types.

Water stress treatment reduced stem length from 66.8 to 50.3 cm in Enrei and from 132.0 to 59.7 cm in Touzan 69, which showed that Touzan 69 is more affected by water stress than Enrei. Under water stress conditions plant height is reduced due to decreased internode elongation and simultaneously the number of nodes on main stem[8]. Our results indicated that in determinate soybean under water stress conditions, suppression of internode elongation resulted in decreased stem length. On the other hand, in indeterminate type both reduced internode elongation and simultaneous decrease in number of main stem nodes resulted in a more shortened stem length as compared to the determinate type.

In Enrei cultivar, water stress reduced stem diameter from 8.49 to 6.89 mm and in Touzan 69 from 8.75 to 5.12 mm. Water stress also reduced the stem weight of Enrei from 10.7 to 5.8 gm and in Touzan 69 from 19.0 to 4.9 gm. These results are quite reasonable because water stress significantly decreased the number of nodes, stem length and stem diameter in both cultivars, which resulted in less stem weight. As these parameters were more adversely affected in Touzan 69 than Enrei, the stem weight was also reduced more in Touzan 69. Egli et al.[4] were of the view that severe water stress treatment in soybean caused large reductions in vegetative plant weight, which is also an indication of reduced plant growth and development.

B. Yield and yield components

1. Flowering and pod set

Water stress reduced the total number of floral buds per plant from 142 to 126 in Enrei and from 243 to 107 in Touzan 69 (Table 2). The floral buds of Touzan 69 were more severely affected by water stress with over 50% reduction. This revealed that genotypes differ in the number of floral buds and also indicates the differences in response to water stress by the two types. Earlier studies too have shown that the production of floral buds differed among cultivars[2] and that water stress in soybean resulted in fewer flowers produced[15].

The number of floral buds were decreased on the main stem from 88 to 75 and on branches from 54 to 51 in Enrei and from 128 to 65 on the main stem and from 115 to 42 on branches in Touzan 69 under water stress conditions. It is clear that on main stem and branches more number of floral

Table 2 Number of floral buds in soybean cultivars as affected by moisture stress

Variety	Plot	Number of floral buds on main stem			No. of floral buds on branches			Total number of floral buds per plant		
		LOR	HOR	Total	LOR	HOR	Total	LOR	HOR	Total
Enrei	Wet	17±2.3^{NS}	71±4.5^{NS}	88±4.9^{NS}	36±4.1^{NS}	18±0.5^{NS}	54±4.7^{NS}	53±5.2^{NS}	89±4.0^{NS}	142±3.4^{NS}
	Dry	17±4.0	58±19.6	75±21.0	34±6.6	17±11.9	51±16.5	51±10.6	75±31.0	126±36.2
Touzan 69	Wet	60±12.7*	68±10.8^{NS}	128±16.0*	87±44.0^{NS}	28±23.4^{NS}	115±67.4^{NS}	147±50.6^{NS}	96±33.5^{NS}	243±82.3^{NS}
	Dry	29±12.5	36±17.9	65±30.4	32±13.3	10±10.0	42±23.2	61±24.5	46±27.0	107±51.3

LOR and HOR indicate the low and high order racemes ^{NS} and * indicate non-significance and 5% level of significance between plots, respectively. Mean of 3 plants±standard deviation.

buds were decreased in Touzan 69 than Enrei. The number of floral buds were decreased almost in the same proportion on main stem and branches in Enrei, therefore the percent contribution of floral buds remained similar even under stress conditions (Fig. 1). In Touzan 69 on the other hand, water stress effect was more evident on the branches than on the main stem, hence the percent contribution on the main stem was increased 8% and decreased in the same proportion on the branches. As regards the low and high order racemes on main stem and branches, it is obvious that both raceme orders at main stem and branches were more adversely affected in Touzan 69 than Enrei, but the effect within the cultivars was similar, so the percent contribution under stress conditions remained stable.

In Enrei water stress reduced the total pod-setting ratio by 4 points (Table 3). In Enrei total pod-setting ratio was decreased only at low order racemes, whereas high order racemes were less susceptible to water stress. On the other hand in Touzan 69 the pod-setting ratio was decreased both at low and high order racemes, therefore the reduction (6 points) in total pod-setting ratio was 2 points more than in Enrei. Other reports[10,11] also revealed that water stress reduced the extent of pod-set and that the effect varies with the cultivar. It was also observed that low order racemes were more susceptible to water stress as compared to high order racemes, especially in Touzan 69.

Pod-setting ratio on main stem and branches was affected differently between the cultivars and even within the cultivars. Pod-setting percentage varies at various locations in the plant[12]. In Enrei branches were more susceptible to water stress, whereas pod-setting ratio on main stem was stable, while in Touzan 69 branches were stable to water stress but pod-setting ratio was a little decreased on the main stem due to water stress.

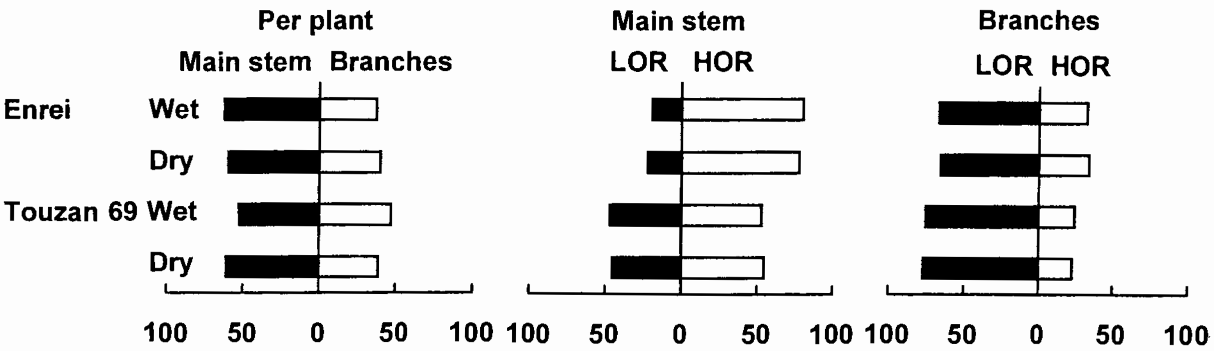

Fig. 1 Percent contribution to the number of floral buds at different plant positions.
LOR: Low order racemes. HOR: High order racemes.

Table 3 Pod-setting ratio (%) in soybean cultivars as affected by moisture stress

Variety	Plot	Pod-setting ratio on main stem			Pod-setting ratio on branches			Total pod-setting ratio per plant		
		LOR	HOR	Total	LOR	HOR	Total	LOR	HOR	Total
Enrei	Wet	60 ± 18.0^{NS}	69 ± 4.7^{NS}	67 ± 2.9^{NS}	54 ± 7.9^{NS}	70 ± 12.4^{NS}	59 ± 1.9^{NS}	56 ± 4.0^{NS}	69 ± 5.4^{NS}	64 ± 1.8^{NS}
	Dry	54 ± 12.6	69 ± 8.7	65 ± 3.9	47 ± 6.0	73 ± 35.1	52 ± 10.0	50 ± 5.4	68 ± 13.7	60 ± 5.5
Touzan 69	Wet	56 ± 18.0^{NS}	47 ± 1.0^{NS}	51 ± 7.6^{NS}	52 ± 11.7^{NS}	17 ± 7.1^{NS}	44 ± 10.1^{NS}	54 ± 7.6^{NS}	40 ± 2.5^{NS}	48 ± 5.6^{NS}
	Dry	44 ± 14.6	33 ± 11.6	39 ± 5.5	47 ± 13.1	32 ± 38.5	46 ± 15.8	45 ± 1.7	36 ± 16.7	42 ± 7.8

LOR and HOR indicate the low and high order racemes, respectively. NS indicates non-significance between plots. Mean of 3 plants±standard deviation.

Although water stress reduced the number of floral buds and pod setting ratio in both soybean types, the effects were not significant. This may be due to the little number of samples (3) for these both parameters with large standard deviations. It was also observed that due to water stress large number of floral buds were reduced as compared to pod setting ratio which may be attributed to severe reduction in the number of nodes per plant in both types.

2. Number of pods

The number of pods per plant were reduced from 74 to 43 in Enrei and from 119 to 26 in Touzan 69 (Table 4) under water stress conditions. This revealed that the effect of water stress in terms of the reduction in the number of pods per plant was more in Touzan 69 than in Enrei. The reduction in the number of pods reported here was a result of fewer floral buds per plant as a result of fewer nodes and an increase in flower and pod abortion (decrease in pod-setting ratio). These results are in agreement with previous reports[7,11,17] in which water stress reduced the number of pods per plant.

In Enrei, water stress effect on the pods at main stem and branches was almost quantitatively similar, therefore the percent contribution to the number of pods on main stem and branches remained stable (Fig. 2). In Touzan 69, the effect on the main stem was less than on the branches, therefore the share of pods on main stem increased 16 points and decreased on branches by 16 points under water stress conditions. The higher reduction of floral buds on branches as compared to main stem under water stress conditions may be the major factor in reducing the number of pods on branches.

Water stress reduced more pods at low order racemes than at high order racemes in Enrei, hence the percent contribution of low order racemes decreased 11% and increased at high order racemes on the main stem. A similar trend, that is an increase in pod share at high order racemes was also noted in Enrei at the branches. This behavior was quite in line to the pod-setting ratio, because in Enrei pod-setting ratio both at

Table 4 Effect of moisture stress on the yield and yield components

Variety	Plot	Number of pods/plant	Seed-setting ratio (%)	Seed number per pod	Seed number per plant	100-seed wt. (g)	Seed yield per plant (g)
Enrei	Wet	74±9.5#	72±9.4#	1.7±0.1#	116±22.3#	27.7±2.1#	31.9±5.9#
	Dry	43±9.0	45±8.1	1.5±0.1	41±14.2	22.5±1.5	9.4±3.5
Touzan 69	Wet	119±22.1#	82±5.1#	1.9±0.1#	206±43.2#	23.2±1.0#	47.7±9.0#
	Dry	26±17.1	43±17.6	1.6±0.2	29±23.5	18.2±1.9	5.4±4.7

# indicates the siginificance at 1% probability level between plots. Mean of 14 plants±standard deviation.

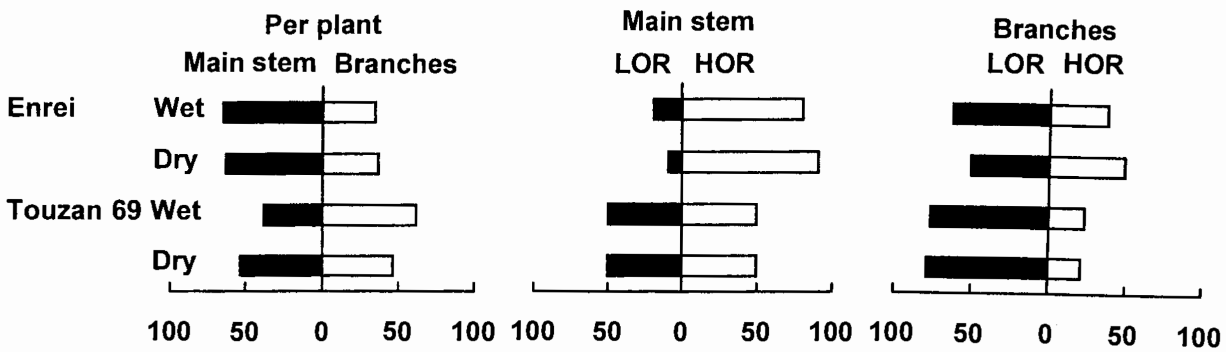

Fig. 2 Percent contribution to the number of pods at different plant positions.
LOR: Low order racemes. HOR: High order racemes.

main stem and branches decreased at low order racemes.

In Touzan 69 the effect of moisture stress at low and high order racemes within the main stem and branches was similar, therefore the percent contribution of low and high order racemes on the main stem and branches remained stable.

3. Number of seeds per plant

It is obvious that water stress seriously reduced the number of seeds per plant, in Enrei from 116 to 41 and in Touzan 69 from 206 to 29 (Table 4). This decrease in the number of seeds per plant under stress conditions is quite in line with previous reports[7,17].

In our experiment the effect was more pronounced in Touzan 69. A review of the whole data indicated that a decrease in the number of nodes reduced the number of floral buds per plant, and a reduced number of floral buds and pod-setting ratio reduced the number of pods per plant in both soybean types. Furthermore, water stress significantly reduced the seed-setting ratio and the number of seeds per pod (Table 4). Since these effects were quantitatively more in Touzan 69, more seeds per plant were decreased in Touzan 69 (86%) than in Enrei (65%).

The difference between the number of seeds at low and high order racemes was mostly attributed to the difference in the number of pods at the respective plant positions (raceme orders). Although both low and high order racemes were affected more in Touzan 69 than in Enrei, the contribution of seeds on low and high order racemes on main stem and branches remained unaffected. However, in Enrei the percent contribution of high order racemes increased under stress conditions because the effect of a reduction in the number of seeds per plant was greater at low order racemes as compared to high order racemes. In Touzan 69, moisture stress increased the contribution of number of seeds on main stem by 17% and decreased the contribution on branches due to higher reduction in the number of seeds on branches.

4. 100-seed weight

Water stress significantly reduced the 100-seed weight in Enrei by 19%, from 27.7 to 22.5 gm and in Touzan 69 by 22%, from 23.2 to 18.2 gm (Table 5). This indicates that 100-seed weight in Touzan 69 is more susceptible to water stress than Enrei. Other workers have also found that 100-seed weight can be reduced by between 14-32% under water stress conditions[1,3,5] which is within the range of decrease in 100-seed weight in our results. Water stress accelerates the senescence and shortens the seed-filling period, so ultimately seed size reduces[3].

In previous reports data on 100-seed weight according to different raceme orders at main stem and branches have not been mentioned. Our results showed that 100-seed weight at main stem and branches both on low and high order racemes was significantly reduced due to water stress in both types. The reduction in 100-seed weight at main stem and branches in Enrei was almost equal (19%) and the effect on low and high order

Table 5 100-seed weight (g) in soybean cultivars as affected by moisture stress

Variety	Plot	100-seed weight on main stem			100-seed weight on branches			Total 100-seed weight per plant		
		LOR	HOR	Total	LOR	HOR	Total	LOR	HOR	Total
Enrei	Wet	29.4±2.8#	27.8±2.2#	28.2±2.2#	26.9±2.8#	25.8±2.8#	26.6±2.4#	27.8±2.4#	27.6±2.1#	27.7±2.1#
	Dry	23.0±4.3	22.9±1.9	22.9±1.9	22.1±2.0	21.6±2.8	21.7±1.8	22.4±2.1	22.6±1.6	22.5±1.5
Touzan 69	Wet	24.6±1.2#	23.0±1.2#	23.8±1.0#	23.0±1.2#	22.3±1.5#	22.9±1.2#	23.5±1.1#	22.8±1.0#	23.2±1.0#
	Dry	19.1±2.1	17.7±2.8	18.7±2.2	17.7±1.8	16.3±3.0	17.6±1.7	18.5±1.5	17.3±2.6	18.2±1.9

LOR and HOR indicate the low and high order racemes, respectively. # indicates the significance at 1% probability level between plots. Mean of 14 plants±standard deviation.

racemes was also about the same amount. In Touzan 69 water stress reduced the 100-seed weight by about 22% on the main stem and branches. Low and high order racemes at main stem followed the same trend of reduction, but at branches 100-seed weight was more reduced (27%) on high order racemes than on low order racemes (22%). This explains why the overall effect on high order racemes in Touzan 69 was more than on low order racemes.

The results made it clear that water stress reduces 100-seed weight more in Touzan 69 as compared to Enrei. Also in Enrei the effect on low and high order racemes at main stem and branches is equal, whereas, in Touzan 69 high order racemes at branches are more vulnerable to water stress than low order racemes. Therefore in Touzan 69 low and high order racemes behave a little different for 100-seed weight under water stress conditions.

5. Seed yield

A serious decline in yield under water stress conditions in both cultivars was observed (Table 4). These results are in accordance with previous findings[1,6] and are due to reductions in the growth and yield components under water stress conditions. As all the growth and yield components were decreased more in Touzan 69, its yield was reduced (89%) more in Touzan 69 than in Enrei (71%).

The seed yield under water stress and irrigated conditions at different plant positions followed the trend observed for the number of pods, i.e., in Enrei branch and stem are equally affected by water stress but low order racemes on both positions are affected more as compared to high order racemes. In Touzan 69 branches are more affected by water stress as compared to main stem but low and high order racemes on both positions are almost equally affected. Other scientists[5,17] are also of the view that the differences in number of pods and seeds per plant among irrigated and non-irrigated conditions essentially mimicked differences in seed yield.

In Touzan 69, seed yield under irrigated conditions was greater than in Enrei, but under water stress conditions it could not maintain this advantage, because of the more adverse effect on all yield components than Enrei. Thseng and Wu[16] have indicated that genotypes which have a high yield potential in a high or optimum input management system may not have the same potential in low input system, and further that genotypes with high yield potential under high input conditions tend to lose more under low input conditions. Exactly the same results have been confirmed in this experiment.

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土壌水分の低下がダイズ品種の生育と収量に及ぼす影響
―― 有限伸育型品種と無限伸育型品種の比較 ――

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有限伸育型ダイズ品種‘エンレイ’と無限伸育型品種‘東山69号’を供試し，適宜灌水を行った湿潤区と播種直後以降全く灌水を行わなかった乾燥区を設けて雨よけ栽培を行った．両品種ともに乾燥区の生育，収量および収量構成要素は湿潤区に比べ著しく低下したが，その程度は‘エンレイ’に比べ‘東山69号’で著しかった．乾燥区の莢数は湿潤区に比べ‘エンレイ’で42％，‘東山69号’では78％減少したが，これには結莢率の低下よりも花蕾数の減少が大きく影響していた．莢数と収量を高次位と低次位の莢に分けてみると，水分ストレスにより‘エンレイ’では低次位の占有割合が低下したのに対して，‘東山69号’では変化しなかった．同様に主茎と分枝に分けてみると，‘東山69号’では主茎の占有割合は増加したのに対して，‘エンレイ’では変化しなかった．すなわち，水分ストレスにより‘エンレイ’では低次位花房が，‘東山69号’では分枝がより大きく影響を受けることがわかった．乾燥区の結実率，百粒重は湿潤区に比べ著しく低下したが，その程度の品種間差は小さかった．長期の水分ストレスに遭遇した場合，有限伸育型品種に比べ無限伸育型品種では生育の停滞，ひいては節数の低下を招き，さらに花蕾数が減少する結果，莢数ひいては収量の低下が著しくなることが推察された．